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# Research of Dr. Kevin D. Jones: Experimental Aerodynami

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There are several experimental projects that I have been involved in, but currently only the Micro Air Vehicle (MAV) project is included here. As time permits, several other projects will be added.

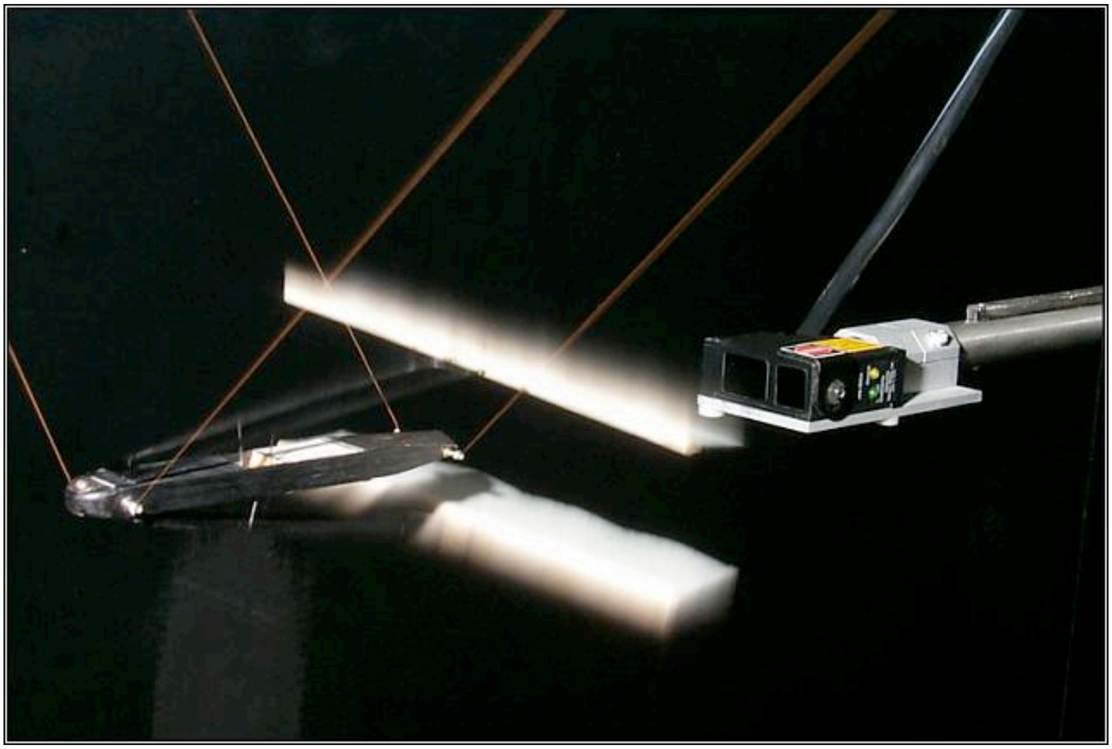
Our contribution to Micro Air Vehicle technology involves the development of flapping-wing propulsion, unconventional by human standards, but clearly the norm in the animal kingdom. There are several arguments in support of flapping-wing propulsion, the most common being that since evolution has selected flapping-wings, they must be optimal. However, this is not necessarily a valid argument. While one cannot easily argue against the principle of optimization inherent in an evolutionary process, one must consider the initial conditions and constraints imposed on the process. For example, we do not see many creatures in nature with rotating parts, therefore I would suggest that evolution did not choose flapping-wings over propellers; but rather propellers were eliminated due to organic constraints. Nevertheless, there are flight regimes where flapping-wings do appear to be superior, in particular, for small, slow-flying vehicles.

While flapping-wing model aircraft have been around for more than a century, almost all previous designs have been bio-mimetic, basically trying to imitate bird or insect mechanics, but with far fewer degrees of freedom. Our approach has been a little different. We look at typical bird-like flapping and see several flaws; things that cannot be easily changed by evolution. Keep in mind that birds and insects have been optimized for a wide variety of tasks, whereas we may design or vehicle for a small subset, perhaps efficient cruising flight and maybe some maneuvering criteria. Some of the flaws are that the plunge amplitude of a bird's wings varies along the span, such that the root portion contributes little to the thrust. Additionally, when a bird flaps its wings up and down, the inertial and aerodynamic loads cause the body to oscillate in opposition, and the work done to accelerate the body is essentially wasted energy.

Our philosophy has been to not limit ourselves to the same constraints as biological systems, but rather to observe how animals which were subject to these constraints have adapted their behavior to compensate for limitations. The most obvious adaptation we could see was the propensity of birds to fly in ground effect, as seen in the photos below of the Brown Pelican, flying over Monterey Bay, and the Great Egret flying over Elkhorn Slough. By flying low over the water the birds experience favorable wake interference, getting increased thrust at an increased efficiency.


While the birds can only benefit from ground effect when they are close to the ground, we have devised a scheme that gives us the benefit of ground effect without having to be near the ground. Additionally, the configuration is aerodynamically and mechanically balanced, so we minimize energy spent accelerating non lifting surfaces, and the main body is a more stable platform for controls and instrumentation.

The model shown below is one of our *15cm*-scale flapping-wing Micro Air Vehicle (MAV) propulsion test models. It was designed as part of an ongoing research program to develop small remotely piloted or autonomous vehicles that utilize flapping wings for propulsion. Details of the model and some of our early results can be found in the cited papers. The models are constructed primarily from balsa-wood, thin graphite/epoxy laminates and micro-film. They are typically powered by small brushless stepping motors or DC pager motors that are about *5mm* in diameter and *12-25mm* long. The motors are geared down to with either a 25:1 planetary gear drive (stepping motors) or a multi-stage spur-gear drive system to yield flapping frequencies between about 18 and 40 Hz. The model shown below is used to evaluate wing designs and flapping motions for optimal thrust generation. It has a mass of just under 6 grams, and a maximum flapping frequency of about 40Hz. You can see a short animation of a similar model performing a vertical takeoff here. The VTO model has a flying weight of about 9 grams.



To measure thrust, the model is suspended from a splitter-plate on 4 very thin (0.003 inch dia) copper wires. The wires allow the model to swing freely in the streamwise direction, but hold it rigidly in the other directions. The model is displaced in the streamwise direction due to drag or thrust, and the displacement is measured using a laser range-finder, reflecting the laser off a small panel on the rear of the model.

Work is being done now to integrate the flapping-wing propulsion systems into complete radio controlled flying models. The models use 3-channel radio gear that weighs just under 4 grams for a receiver, electronic speed control, and two voice-coil servos. We power the systems with 3.7Volt 135mHr rechargeable Li-ion polymer batteries that weigh about 3 grams, and we build tiny .5gram DC-DC step-up circuits that bump the battery voltage up to a regulated 5 volts. The complete models weigh in at about 14 grams. For info about the flying model shown in the figure below, check out the last paper cited below, or look at the videos of the first few flights.

- First flight: first 27 seconds of about a 1 minute flight. (763kb WMV file)
- Second flight: full 2 minute flight, including recovery from tree (3.767Mb WMV file)

**Breaking News:** we have a new, smaller model with rudder control and a 13.5 gram total weight. Several videos are linked below. It made its first public appearance at an AIAA-sponsored technical seminar at NASA Ames on February 12th. Due to rain, the flight demonstration was moved into the test section of the 80 by 120 foot National Full-Scale Aerodynamics Complex, the worlds largest wind tunnel. I guess we can now advertise that NASA sponsored the wind-tunnel testing of our 10-inch span micro-UAV.

- First flight of Model 2: full 3 minute flight of the model shown in the carrying case at the top of the page. The new model has rudder control, and enough battery power for at least a 20 minute flight. The 3 minute flight used about 1/20th of the battery's capacity. Warning, it was a windy day, and along with the higher flight speed and the ability to turn without notice, the cameraman had a tough time keeping up. (4.847Mb WMV file)

- Flight in the NFAC 80x120 test section: most of a 3:35 minute flight in the NFAC 80x120 test section. Due to the anechoic walls of the tunnel, the gear and flapping noise of the model, which are usually drowned out by background noise, can actually be heard.

**Relevant Publications:**


Jones, K.D., Dohring, C.M. and Platzer, M.F., "An Experimental and Computational Investigation Of the Knoller-Betz Effect," **AIAA Journal** Vol. 36, No. 7, 1998, pp. 1240-1246.

Jones, K.D., Dohring, C.M. and Platzer, M.F., "Wake Structures Behind Plunging Airfoils: A Comparison of Numerical and Experimental Results," AIAA Paper No. 96-0078, *34th AIAA Aerospace Sciences Meeting*, Reno, Nevada, Jan., 1996.

Jones, K.D. and Center, K.B., "Numerical Wake Visualization for Airfoils Undergoing Forced and Aeroelastic Motions," AIAA Paper No. 96-0055, *34th AIAA Aerospace Sciences Meeting*, Reno, Nevada, Jan., 1996.

Jones, K.D. and Platzer, M.F., "Numerical Computation of Flapping-Wing Propulsion and Power Extraction," AIAA Paper No. 97-0826, *35th AIAA Aerospace Sciences Meeting*, Reno Nevada, Jan., 1997.

Jones, K.D. and Platzer, M.F., "An Experimental and Numerical Investigation of Flapping-Wing Propulsion," AIAA Paper No. 99-0995, *37th AIAA Aerospace Sciences Meeting*, Reno, Nevada, Jan., 1999.

Jones, K.D., Davids, S. and Platzer, M.F., "Oscillating-Wing Power Generator," ASME/JSME Joint Fluids Engineering Conference, San Francisco, CA, July 18-23, 1999.

Jones, K.D. and Platzer, M.F., "Flapping-Wing Propulsion for a Micro Air Vehicle," AIAA Paper No. 2000-0897, *38th AIAA Aerospace Sciences Meeting*, Reno, Nevada, Jan., 2000.

Jones, K.D., Lund, T.C. and Platzer, M.F., "Experimental and Computational Investigation of Flapping-Wing Propulsion for Micro Air Vehicles," *Conference on Fixed, Flapping and Rotary Wing Vehicles at Very Low Reynolds Numbers,* Notre Dame, Indiana, June 5-7, 2000.

Jones, K.D., Castro, B.M., Mahmoud, O., Pollard, S.J., Platzer, M.F., Neef, M., Gonet, K. and Hummel, D., "A Collaborative Numerical and Experimental Investigation of Flapping-Wing Propulsion," AIAA Paper No. 2002-0706, Reno, Nevada, Jan. 2002.

Jones, K.D., Castro, B.M., Mahmoud, O. and Platzer, M.F., "A Numerical and Experimental Investigation of Flapping-Wing Propulsion in Ground Effect," AIAA Paper No. 2002-0866, Reno, Nevada, Jan. 2002.

Jones, K.D. and Platzer, M.F., "Experimental Invesitigation of the Aerodynamic Characteristics of Flapping-Wing Micro Air Vehicles" AIAA Paper No. 2003-0418, Reno, Nevada, Jan. 2003.